METHOD OF TREATING AND PREVENTING INFECTIONS IN IMMUNOCOMPROMISED SUBJECTS WITH IMMUNOSTIMULATORY CpG OLIGONUCLEOTIDES

PRIORITY CLAIM

This claims the benefit of U.S. Provisional Patent Application No. 60/411,944 filed September 18, 2002, which is incorporated by reference herein in its entirety.

FIELD

The present disclosure relates to a method of increasing an immune response to an opportunistic infection in an immunocompromised subject or a subject infected with a lentivirus, specifically to a method of increasing an immune response to a pathogen using oligodeoxynucleotides including a CpG.

BACKGROUND

Primary disorders of the immune system can be divided into four categories, (1) disorders of the humoral immunity, (2) disorders of cellular immunity, (3) disorders of phagocytes, and (4) disorders of complement. In addition, there are many causes of secondary immunodeficiency such as treatment with immunosuppressive or chemotherapeutic agents, protein-losing enteropathy, and infection with a human immunodeficiency virus (HIV). Generally, immunocompromised patients are unable to mount an immune response to a vaccine or an infection in the same manner as non-immunocompromised individuals.

Acquired immunodeficiency syndrome (AIDS) is a disease characterized by a progressive loss of function of the immune system. As a result, those afflicted with the syndrome are susceptible to a variety of opportunistic infections. The etiologic agent of AIDS is a cytopathic retrovirus designated the human immunodeficiency virus (HIV). One of the major targets of the HIV in humans is T helper cells (CD4+ cells). The infection of T helper cells by HIV results in a profound dysregulation of the immune system that includes both depleted numbers and impaired function of T lymphocytes.

Although the exact mechanism is unknown, the number of T helper cells predictably declines during HIV infection. Clinicians monitor this decline as an indicator of disease progression.

Opportunistic infections to which individuals infected with HIV are susceptible include bacterial infections such as salmonellosis, syphilis and neurosyphilis, turberculosis (TB), atypical mycobacterial infection, and bacillary angiomatosis (cat scratch disease), fungal infections such as aspergillosis, candidiasis (thrush, yeast infection), coccidioidomycosis, cryptococcal meningitis, and histoplasmosis, protozoal infections such as cryptosporidiosis, isosporiasis, microsporidiosis, *Pneumocystis Carinii* pneumonia (PCP), and toxoplasmosis, viral infections such as *Cytomegalovirus* (CMV), hepatitis, herpes simplex (HSV, genital herpes), herpes zoster (HZV, shingles), human papiloma virus (HPV, genital warts, cervical cancer), *Molluscum Contagiosum*, oral hairy leukoplakia (OHL), and progressive multifocal leukoencephalopathy (PML), and neoplasms such as Kaposi's sarcoma, systemic non-Hodgkin's lymphoma (NHL), and primary CNS lymphoma, among others. These opportunistic infections remain principally responsible for the morbidity and mortality associated with HIV disease.

In view of the above, there exists a need for agents that act as immunoprotective agents in immunocompromised individuals.

SUMMARY

Described herein are methods of increasing an immune response to an opportunistic infection in an immunocompromised subject. In one embodiment, the method includes administering to the subject a therapeutically effective amount of an immunostimulatory D oligodeoxynucleotide including a CpG motif, thereby increasing the response to the opportunistic infection. In another embodiment, the method includes administering to the subject a therapeutically effective amount of an immunostimulatory K oligodeoxynucleotide including a CpG motif, thereby increasing the response to the opportunistic infection.

In some embodiments, the subject is infected with a lentivirus, for example, a human immunodeficiency virus or a simian immunodeficiency virus. In some embodiments, the ODN is administered alone, whereas in other embodiments, the ODN is administered in combination with drugs that comprise a highly active anti-retroviral therapy (HAART), for example an anti-retroviral drug such as 3'-azido-3'dexoy-thymidine (AZT).

In other embodiments, the oligodeoxynucleotide is at least about 16 nucleotides in length and includes a sequence represented by the following formula:

5' $X_1X_2X_3$ Pu_1 Py_2 CpG Pu_3 Py_4 $X_4X_5X_6(W)_M$ $(G)_N$-3' (SEQ ID NOs: 22-98)

wherein the central CpG motif is unmethylated, Pu is a purine nucleotide, Py is a pyrimidine nucleotide, X and W are any nucleotide, M is any integer from 0 to 10, and N is any integer from 4 to 10. In certain examples, Pu Py CpG_Pu Py includes phosphodiester bases, and in certain examples, $X_1X_2X_3$ and $X_4X_5X_6(W)_M$ $(G)_N$ includes phosphodiester bases. In some examples, $X_1X_2X_3$ Pu Py and Pu Py $X_4X_5X_6$ are self complementary.

In still other embodiments, the method is a method of increasing an immune response to an opportunistic infection in an immunocompromised subject, including administering to the subject a therapeutically effective amount of an immunostimulatory D oligodeoxynucleotide, thereby increasing the immune response to the opportunistic infection. In yet still other embodiments, the method is a method of increasing an immune response to an opportunistic infection in an immunocompromised subject, including administering to the subject a therapeutically effective amount of an immunostimulatory D oligodeoxynucleotide or an immunostimulatory K oligodeoxynucleotide, wherein an antigenic epitope of a polypeptide is not administered to the subject, thereby increasing the response to the opportunistic infection.

The foregoing and other features and advantages will become more apparent from the following detailed description of several embodiments, which proceeds with reference to the accompanying figures.

BRIEF DESCRIPTION OF THE FIGURES

FIG. 1 is a set of graphs showing the response of primate peripheral blood mononuclear cells (PBMC) to K and D oligonucleotides (ODN). PBMC from 8-20 normal human donors and 20 rhesus macaques were stimulated for 72 hours with a panel of K, D or control ODN (3 mM). IL-6 and IFNα levels in culture supernatants were determined by ELISA while cell proliferation was assessed by $[H]^3$ thymidine uptake. Note that D ODN induce the secretion of IFNα while K ODN induce cell proliferation and IL-6 producton. The response of PBMC from rhesus macaques mirrors that of human PBMC. All assays were performed in triplicate. Statistical significance was determined by ANOVA of log normalized data. A single asterisk (*) indicates a P value of <0.05; a double asterisk (**) indicates a P value of <0.01.

FIG. 2 is a graph showing that treatment of primates with CpG D ODN protects them from a local challenge with pathogenic *Leishmania* parasites. Treatment of the macaques with D ODN, but not with K ODN, significantly reduced the size of the cutaneous lesion ($p<0.001$).

FIG. 3 is a set of graphs showing that D ODNs trigger the secretion of IFNα and IFNγ. In contrast, K ODNs increase cell proliferation and IL-6 production. PBMC from healthy and HIV infected subjects secreted similar levels of IFNα and IFNγ in the absence of stimulation or in the presence of control ODN lacking the CpG motif. Upon stimulation with CpG D ODN, however, PBMC from HIV infected subjects generated significantly lower IFNγ ($p<0.05$) or IFNα than healthy controls ($p<0.001$).

FIG. 4 is a graph showing that D ODNs induce dendritic cell (DC) maturation.

FIG. 5 is a set of graphs demonstrating that the response to K ODNs is not significantly different in PBMC from HIV infected and healthy subjects, indicating that B cells and monocytes retain their ability to respond to CpG ODN. These data show

that PBMC from HIV infected subjects are activated by CpG ODN *in vitro*. The responsiveness to CpG ODN, although reduced, is evident even among patients with high viral loads and low CD4+T cells. The reduction in IFNα and IFNγ secretion correlated directly with the number of CD4+ T cells ($p<0.01$).

FIG. 6 is a set of graphs showing that, as observed with PBMC from HIV infected patients, PBMC from SIV infected macaques showed a response to CpG K ODN stimulation *in vitro* that was indistinct from that of healthy macaques. Stimulation with CpG D ODNs, in turn, generated significantly increased levels of IFNα, although the magnitude of the IFNα response was reduced when compared with PBMC from healthy macaques.

FIG. 7 is a graph showing lesion size in SIV-infected rhesus macaques challenged with *L. Major*. Fourteen rhesus macaques that had been infected with XX SIV strain mac239 a year before the start of the study (Viral load range: 0.3-28 $x10^6$ copies/ml) were utilized. Monkeys were treated intradermally with D ODNs (n=4), K ODNs (n=4), control ODNs (n=3) or saline 3 days before and 3 days after an intradermal challenge with 10^7 viable metacyclic promastigotes of *L. major* (WHOM/IR/-/173), a strain of *Leishmania* that frequently infects HIV patients. Control monkeys developed a typical self-limited *in situ* lesion characterized by erythema, induration, and ulceration. The lesion size, which reflects the severity of infection, was measured weekly. Monkeys treated with D ODNs had significantly smaller lesions than control or K ODN treated monkeys. The protection afforded to SIV infected macaques was comparable to that obtained in healthy monkeys.

FIG. 8 is a graph showing the effect of D and K ODN as adjuvants to the hepatitis B vaccine in rhesus macaques. Macaques (five/group) were immunized with Engerix-B (10 μg) alone or together with D or K ODN (250 μg/dose) on days 1, 30 and 60 of the study. Levels of IgG anti-hepatitis B surface antigen (HbsAg) were monitored

by ELISA every two weeks. Macaques that received D or K ODN together with the vaccine developed significantly higher antibody levels compared to those that received the vaccine alone ($p<0.01$).

FIG. 9A-B is a pair of graphs showing that D and K ODN boost the immunogenicity of Engerix B in SIV-infected rhesus macaques. SIV infected macaques were immunized on days 1, 30 and 75 with Engerix-B alone (n=5) or together with D or K ODN (n=6/group). Levels of IgG anti-HbsAg were monitored as described in Example 8. **FIG. 9A** is a graph showing the correlation of individual viral loads at the start of the study with the antibody titers developed 45 days after the prime and 45 days after the last immunization. One macaque from the group that received D ODN was euthanized during the study because of intractable diarrhea and weight loss attributed to the SIV infection. **FIG. 9B** is a graph showing the anti-HbsAg antibody levels by animals with viral loads $<10^7$ copies/ml (n=4/group). Animals that received the vaccine alone were unable to mount an antibody response, while those that received K or D ODN together with the HBV vaccine developed significant antibody levels.

SEQUENCE LISTING

The nucleic acid sequences listed in the accompanying sequence listing are shown using standard letter abbreviations for nucleotide bases, as defined in 37 C.F.R. 1.822. In the accompanying sequence listing:

SEQ ID NOs: 1-16 are immunostimulatory CpG oligonucleotide sequences.

SEQ ID NOs: 17-18 are SIV primer sequences.

SEQ ID NO: 19 is an SIV-specific probe.

SEQ ID NO: 20 is a K ODN that includes at least about 10 nucleotides described by Formula I.

SEQ ID NO: 21 is a CpG motif in D oligonucleotides described by Formula II.

SEQ ID NOs: 22-98 are immunostimulatory CpG oligonucleotide sequences

SEQ ID NOs: 99-175 are oligodeoxynucleotides that include a sequence represented by Formula IV.

SEQ ID NO: 176 is immunostimulatory CpG oligonucleotide sequence D19.

SEQ ID NO: 177 is immunostimulatory CpG oligonucleotide sequence D35.

SEQ ID NO: 178 is immunostimulatory CpG oligonucleotide sequence D29.

SEQ ID NO: 179 is immunostimulatory CpG oligonucleotide sequence K3.

SEQ ID NO: 180 is immunostimulatory CpG oligonucleotide sequence K123.

SEQ ID NO: 181 is immunostimulatory CpG oligonucleotide sequence K23.

DETAILED DESCRIPTION

I. Abbreviations

A:	adenine
Ab:	antibody
AIDS:	Acquired Immunodeficiency Syndrome
ANOVA:	analysis of variance
APC:	antigen presenting cell
AVT:	3'-azido-3'dexoy-thymidine
BIV:	bovine immunodeficiency virus
BSA:	bovine serum albumin
C:	cytosine
CAEV:	caprine arthritis-encephalitis virus
CpG ODN:	an oligodexoynucleotide (either a D or a K type) including a CpG motif
CGD:	chronic granulomatous disease
CMV:	*Cytomegalovirus*
CNS:	central nervous system
DC:	dendritic cell
DNA:	deoxyribonucleic acid
EIAV:	equine infectious anemia virus

ELISA:	Enzyme-Linked Immunosorbent Assay
env:	envelope
EU:	endotoxin units
FAM:	Carboxyfluorescein
FCS:	fetal calf serum
FDA:	Food ND drug Administration
FIV:	feline immunodeficiency virus
G:	guanine
h:	hour
HAART:	highly active anti-retroviral therapy
HbsAg:	hepatitis B surface antigen
HBV:	hepatitis B virus
HEPES:	4-(2-hydroxyethyl)-1-piperazineethanesulfonic acid
HIV:	human immunodeficiency virus
HIV-1:	human immunodeficiency virus, type 1
HIV-2:	human immunodeficiency virus, type 2
HPV:	human papiloma virus
HSV:	herpes simplex virus
HZV:	herpes zoster virus
i.d.	intradermal
IFN-α:	interferon alpha
IFN-γ:	interferon gamma
μg:	microgram
mm:	millimeter
mRNA:	messenger ribonucleic acid.
NA:	nucleoside analog reverse transcriptase inhibitor
NADPH:	nicotine amide dinucleotide phosphatase
NHL:	non-Hodgkin's lymphoma
NIH:	National Institutes of Health

NK:	natural killer cells
NNRTI:	non-nucleoside analog reverse transcriptase inhibitor
ODN:	oligodeoxynucleotide
OHL:	oral hairy leukoplakia
ORF:	open reading frame
ORN:	oligoribonucleotide
PBMC:	peripheral blood mononuclear cells
PBS:	phosphate buffered saline
PCP:	*Pneumocystis Carinii* pneumonia
PCR:	polymerase chain reaction
pDC:	plasmacytoid dendritic cells
PI:	protease inhibitor
PML:	progressive multifocal leukoencephalopathy
pol:	polymerase
Pu:	purine
Py:	pyrimidine
RNA:	ribonucleic acid
rtPCR:	reverse transcriptase polymerase chain reaction
s.c.:	subcutaneous
SCID:	severe combined immune deficiency
SIV:	simian immunodeficiency virus
SIVagm:	simian immunodeficiency virus, agm
SIVcol:	simian immunodeficiency virus, col
SIVmnd:	simian immunodeficiency virus, mnd
SIVsyk:	simian immunodeficiency virus, syk
T:	thymine
TB:	turberculosis
TNF:	tumor necrosis factor
U:	uracil

TAMRA: carboxytetramethyl rhodamine

VL: viral load

VMV: Visna-Maedi virus

II. Terms

Unless otherwise noted, technical terms are used according to conventional usage. Definitions of common terms in molecular biology may be found in Benjamin Lewin, *Genes V*, published by Oxford University Press, 1994 (ISBN 0-19-854287-9); Kendrew *et al.* (eds.), *The Encyclopedia of Molecular Biology*, published by Blackwell Science Ltd., 1994 (ISBN 0-632-02182-9); and Robert A. Meyers (ed.), *Molecular Biology and Biotechnology: a Comprehensive Desk Reference*, published by VCH Publishers, Inc., 1995 (ISBN 1-56081-569-8).

In order to facilitate review of the various embodiments of this disclosure, the following explanations of specific terms are provided:

AIDS: Acquired immunodeficiency syndrome (AIDS) is a disease characterized by a progressive loss of function of the immune system. As a result, those afflicted with the syndrome are susceptible to a variety of opportunistic infections. The etiologic agent of AIDS is a cytopathic retrovirus designated the human immunodeficiency virus (HIV). One of the major targets of the HIV in humans is T helper cells (CD4+ cells). The infection of T helper cells by HIV results in a profound dysregulation of the immune system that includes both depleted numbers and impaired function of T lymphocytes. Although the exact mechanism is unknown, the number of T helper cells predictably declines during HIV infection. Clinicians monitor this decline as an indicator of disease progression.

Animal: Living multi-cellular vertebrate organisms, a category that includes, for example, mammals and birds. The term mammal includes both human and non-human mammals. Similarly, the term "subject" includes both human and veterinary subjects.

Anti-infectious agent: A substance (such as a chemical compound, protein, antisense oligonucleotide, or other molecule) of use in treating infection of a subject. Anti-infectious agents include, but are not limited to, anti-fungals, anti-virals, and antibiotics.

Antisense, Sense, and Antigene: Double-stranded DNA (dsDNA) has two strands, a 5' -> 3' strand, referred to as the plus strand, and a 3' -> 5' strand (the reverse compliment), referred to as the minus strand. Because RNA polymerase adds nucleic acids in a 5' -> 3' direction, the minus strand of the DNA serves as the template for the RNA during transcription. Thus, the RNA formed will have a sequence complementary to the minus strand and identical to the plus strand (except that U is substituted for T).

Antisense molecules are molecules that are specifically hybridizable or specifically complementary to either RNA or the plus strand of DNA. Sense molecules are molecules that are specifically hybridizable or specifically complementary to the minus strand of DNA. Antigene molecules are either antisense or sense molecules directed to a dsDNA target. In one embodiment, an antisense molecule specifically hybridizes to a target mRNA and inhibits transcription of the target mRNA.

CD4: Cluster of differentiation factor 4 polypeptide, a T-cell surface protein that mediates interaction with the MHC class II molecule. CD4 also serves as the primary receptor site for HIV on T-cells during HIV infection.

The known sequence of the CD4 precursor has a hydrophobic signal peptide, an extracelluar region of approximately 370 amino acids, a highly hydrophobic stretch with significant identity to the membrane-spanning domain of the class II MHC beta chain, and a highly charged intracellular sequence of 40 resides (Maddon, *Cell* 42:93, 1985).

CpG or **CpG motif:** A nucleic acid having a cytosine followed by a guanine linked by a phosphate bond in which the pyrimidine ring of the cytosine is unmethylated. The term "methylated CpG" refers to the methylation of the cytosine on the pyrimidine ring, usually occurring the 5-position of the pyrimidine ring. A CpG motif is a pattern of bases that include an unmethylated central CpG surrounded by at

least one base flanking (on the 3' and the 5' side of) the central CpG. Without being bound by theory, the bases flanking the CpG confer part of the activity to the CpG oligodeoxynucleotide. A CpG oligonucleotide is an oligonucleotide that is at least about ten nucleotides in length and includes an unmethylated CpG. CpG oligonucleotides include both D and K oligodeoxynucleotides (see below). CpG oligodeoxynucleotides are single-stranded. The entire CpG oligodeoxynucleotide can be unmethylated or portions may be unmethylated. In one embodiment, at least the C of the 5' CG 3' is unmethylated.

Cytokine: Proteins made by cells that affect the behavior of other cells, such as lymphocytes. In one embodiment, a cytokine is a chemokine, a molecule that affects cellular trafficking.

Epitope: An antigenic determinant. These are particular chemical groups or peptide sequences on a molecule that are antigenic, for example, that elicit a specific immune response. An antibody binds a particular antigenic epitope. Particular HIV epitopes include, but are not limited to Nef, gag-p24, reverse transcriptase, P17 gag.

Functionally Equivalent: Sequence alterations, for example in a D ODN, that yield the same results as described herein. Such sequence alterations can include, but are not limited to, deletions, base modifications, mutations, labeling, and insertions.

Highly active anti-retroviral therapy (HAART): A combination of drugs which, when administered in combination, inhibits a retrovirus from replicating or infecting cells better than any of the drugs individually. In one embodiment, the retrovirus is a human immunodeficiency virus. In one embodiment, the highly active anti-retroviral therapy includes the administration of 3'axido-3-deoxy-thymidine (AZT) in combination with other agents. Examples of agents that can be used in combination in HAART for a human immunodeficiency virus are nucleoside analog reverse transcriptase inhibitor drugs (NA), non-nucleoside analog reverse transcriptase inhibitor drugs (NNRTI), and protease inhibitor drugs (PI). One specific, non-limiting example of HAART used to suppress an HIV infection is a combination of indinavir and efavirenz, an experimental non-nucleoside reverse transcriptase inhibitor (NNRTI).

In one embodiment, HAART is a combination of three drugs used for the treatment of an HIV infection, such as the drugs shown in Table 1 below. Examples of three drug HAART for the treatment of an HIV infection include 1 protease inhibitor from column A plus 2 nucleoside analogs from column B in Table 1. In addition, ritonavir and saquinavir can be used in combination with 1 or 2 nucleoside analogs.

Table 1

Column A	Column B
indinavir (Crixivan)	AZT/ddI
nelfinavir (Viracept)	d4T/ddI
ritonavir (Norvir)	AZT/ddC
saquinavir (Fortovase)	AZT/3TC
ritonavir/saquinavir	d4T/3TC

In addition, other 3- and 4-drug combinations can reduce HIV to very low levels for sustained periods. The combination therapies are not limited to the above examples, but include any effective combination of agents for the treatment of HIV disease (including treatment of AIDS).

HIV: (human immunodeficiency virus) is a retrovirus that causes immunosuppression in humans (HIV disease), and leads to a disease complex known as acquired immunodeficiency syndrome (AIDS). "HIV disease" refers to a well-recognized constellation of signs and symptoms (including the development of opportunistic infections) in persons who are infected by an HIV virus, as determined by antibody or western blot studies. Laboratory findings associated with this disease are a progressive decline in T-helper cells.

Immune response: A response of a cell of the immune system, such as a B cell or a T cell to a stimulus. In one embodiment, the response is specific for a particular antigen (an "antigen-specific response").

Immune system deficiency: A disease or disorder in which the subject's immune system is not functioning in normal capacity or in which it would be useful to

boost a subject's immune response. In one specific, non-limiting example, a subject with an immune system deficiency has a tumor or cancer (for example, tumors of the brain, lung (for example, small cell and non-small cell), ovary, breast, prostate, colon, or another carcinoma or sarcoma).

Immunocompromised: An immunocompromised subject is a subject who is incapable of developing or unlikely to develop a robust immune response, usually as a result of disease, malnutrition, or immunosuppressive therapy. An immunocompromised immune system is an immune system that is functioning below normal. Immunocompromised subjects are more susceptible to opportunistic infections, for example viral, fungal, protozoan, or bacterial infections, prion diseases, and certain neoplasms. Those who can be considered to be immunocompromised include, but are not limited to, subjects with AIDS (or HIV positive), subjects with severe combined immune deficiency (SCID), diabetics, subjects who have had transplants and who are taking immunosuppressives, and those who are receiving chemotherapy for cancer. Immunocompromised individuals also includes subjects with most forms of cancer (other than skin cancer), sickle cell anemia, cystic fibrosis, those who do not have a spleen, subjects with end stage kidney disease (dialysis), and those who have been taking corticosteroids on a frequent basis by pill or injection within the last year. Subjects with severe liver, lung, or heart disease also may be immunocompromised.

Infectious agent: An agent that can infect a subject, including, but not limited to, viruses, bacteria, and fungi. In one embodiment, an infectious agent is opportunistic.

Examples of infectious virus include: *Retroviridae* (for example, human immunodeficiency viruses, such as HIV-1 (also referred to as HTLV-III, LAV or HTLV-III/LAV, or HIV-III) and other isolates, such as HIV-LP; *Picornaviridae* (for example, polio viruses, hepatitis A virus; enteroviruses, human coxsackie viruses, rhinoviruses, echoviruses); *Calciviridae* (such as strains that cause gastroenteritis); *Togaviridae* (for example, equine encephalitis viruses, rubella viruses); *Flaviridae* (for example, dengue viruses, encephalitis viruses, yellow fever viruses); *Coronaviridae* (for example, coronaviruses); *Rhabdoviridae* (for example, vesicular stomatitis viruses,

rabies viruses); *Filoviridae* (for example, ebola viruses); *Paramyxoviridae* (for example, parainfluenza viruses, mumps virus, measles virus, respiratory syncytial virus); *Orthomyxoviridae* (for example, influenza viruses); *Bungaviridae* (for example, Hantaan viruses, bunga viruses, phleboviruses and Nairo viruses); *Arena viridae* (hemorrhagic fever viruses); *Reoviridae* (for example, reoviruses, orbiviurses and rotaviruses); *Birnaviridae*; *Hepadnaviridae* (Hepatitis B virus); *Parvoviridae* (parvoviruses); *Papovaviridae* (papilloma viruses, polyoma viruses); *Adenoviridae* (most adenoviruses); *Herpesviridae* (herpes simplex virus (HSV)-1 and HSV-2, varicella zoster virus, cytomegalovirus (CMV), herpes viruses); *Poxviridae* (variola viruses, vaccinia viruses, pox viruses); and *Iridoviridae* (such as African swine fever virus); and unclassified viruses (for example, the etiological agents of Spongiform encephalopathies, the agent of delta hepatitis (thought to be a defective satellite of hepatitis B virus), the agents of non-A, non-B hepatitis (class 1=internally transmitted; class 2=parenterally transmitted (for example, Hepatitis C); Norwalk and related viruses, and astroviruses).

Examples of infectious bacteria include: *Helicobacter pyloris, Borelia burgdorferi, Legionella pneumophilia, Mycobacteria sps* (such as. *M. tuberculosis, M. avium, M. intracellulare, M. kansaii, M. gordonae*), *Staphylococcus aureus, Neisseria gonorrhoeae, Neisseria meningitidis, Listeria monocytogenes, Streptococcus pyogenes* (Group A *Streptococcus*), *Streptococcus agalactiae* (Group B *Streptococcus*), *Streptococcus* (*viridans* group), *Streptococcus faecalis, Streptococcus bovis, Streptococcus (anaerobic sps.), Streptococcus pneumoniae, pathogenic Campylobacter sp., Enterococcus sp., Haemophilus influenzae, Bacillus antracis, corynebacterium diphtheriae, corynebacterium sp., Erysipelothrix rhusiopathiae, Clostridium perfringers, Clostridium tetani, Enterobacter aerogenes, Klebsiella pneumoniae, Pasturella multocida, Bacteroides sp., Fusobacterium nucleatum, Streptobacillus moniliformis, Treponema pallidium, Treponema pertenue, Leptospira,* and *Actinomyces israelli.*

Examples of infectious fungi include, but are not limited to, *Cryptococcus neoformans, Histoplasma capsulatum, Coccidioides immitis, Blastomyces dermatitidis, Chlamydia trachomatis,* and *Candida albicans.*

Other infectious organisms (such as protists) include: *Plasmodium falciparum* and *Toxoplasma gondii.*

Isolated: An "isolated" biological component (such as a nucleic acid, peptide or protein) has been substantially separated, produced apart from, or purified away from other biological components in the cell of the organism in which the component naturally occurs, for example, other chromosomal and extrachromosomal DNA and RNA, and proteins. Nucleic acids, peptides and proteins which have been "isolated" thus include nucleic acids and proteins purified by standard purification methods. The term also embraces nucleic acids, peptides and proteins prepared by recombinant expression in a host cell as well as chemically synthesized nucleic acids.

Lentivirus: A genus of the family retroviridae consisting of non-oncogenic retroviruses that produce multi-organ diseases characterized by long incubation periods and persistent infection. Lentiviruses are unique in that they contain open reading frames (orfs) between the polymerase (pol) and envelope (env) genes and in the 3' env region. Five serogroups are recognized, reflecting the mammalian hosts with which they are associated. Lentiviruses include, but are not limited to human immunodeficiency virus, type 1 (HIV-1), human immunodeficiency virus, type 2 (HIV-2), simian immunodeficiency virus, agm (SIVagm), simian immunodeficiency virus, mnd (SIVmnd), simian immunodeficiency virus, syk (SIVsyk), simian immunodeficiency virus, col (SIVcol), Visna-Maedi virus (VMV), bovine immunodeficiency virus (BIV), feline immunodeficiency virus (FIV), caprine arthritis-encephalitis virus (CAEV), and equine infectious anemia virus (EIAV).

Leukocyte: Cells in the blood, also termed "white cells," that are involved in defending the body against infective organisms and foreign substances. Leukocytes are produced in the bone marrow. There are 5 main types of white blood cell, subdivided between 2 main groups: polymorphomnuclear leukocytes (neutrophils, eosinophils,

basophils) and mononuclear leukocytes (monocytes and lymphocytes). When an infection is present, the production of leukocytes increases.

Mammal: This term includes both human and non-human mammals. Similarly, the term "subject" includes both human and veterinary subjects.

Maturation: The process in which an immature cell, such as dendritic cell, changes in form or function to become a functional mature cell, such as an APC.

Nucleic acid: A deoxyribonucleotide or ribonucleotide polymer in either single or double stranded form, and unless otherwise limited, encompasses known analogues of natural nucleotides that hybridize to nucleic acids in a manner similar to naturally occurring nucleotides.

Oligonucleotide or "**oligo**": Multiple nucleotides (for example, molecules comprising a sugar (for example, ribose or deoxyribose) linked to a phosphate group and to an exchangeable organic base, which is either a substituted pyrimidine (Py) (for example, cytosine (C), thymine (T) or uracil (U)) or a substituted purine (Pu) (for example, adenine (A) or guanine (G)). The term "oligonucleotide" as used herein refers to both oligoribonucleotides (ORNs) and oligodeoxyribonucleotides (ODNs). The term "oligonucleotide" also includes oligonucleosides (for example, an oligonucleotide minus the phosphate) and any other organic base polymer. Oligonucleotides can be obtained from existing nucleic acid sources (for example, genomic or cDNA), but are preferably synthetic (for example, produced by oligonucleotide synthesis).

A "stabilized oligonucleotide" is an oligonucleotide that is relatively resistant to *in vivo* degradation (for example via an exo- or endo-nuclease). In one embodiment, a stabilized oligonucleotide has a modified phosphate backbone. One specific, non-limiting example of a stabilized oligonucleotide has a phophorothioate modified phosphate backbone (wherein at least one of the phosphate oxygens is replaced by sulfur). Other stabilized oligonucleotides include: nonionic DNA analogs, such as alkyl- and aryl- phophonates (in which the charged phosphonate oxygen is replaced by an alkyl or aryl group), and phophodiester and alkylphosphotriesters, in which the charged oxygen moiety is alkylated. Oligonucleotides that contain a diol, such as

tetraethyleneglycol or hexaethyleneglycol, at either or both termini have also been shown to be substantially resistant to nuclease degradation.

An "immunostimulatory oligonucleotide," "immunostimulatory CpG containing oligodeoxynucleotide," "CpG ODN," refers to an oligodeoxynucleotide, which contains a cytosine, guanine dinucleotide sequence and stimulates (for example, has a mitogenic effect) vertebrate immune cells. The cytosine, guanine is unmethylated.

An "oligonucleotide delivery complex" is an oligonucleotide associated with (for example, ionically or covalently bound to; or encapsulated within) a targeting means (for example, a molecule that results in a higher affinity binding to a target cell (for example, a B-cell or natural killer (NK) cell) surface and/or increased cellular uptake by target cells). Examples of oligonucleotide delivery complexes include oligonucleotides associated with: a sterol (for example, cholesterol), a lipid (for example, a cationic lipid, virosome or liposome), or a target cell specific binding agent (for example, a ligand recognized by a target cell specific receptor). Preferred complexes must be sufficiently stable *in vivo* to prevent significant uncoupling prior to internalization by the target cell. However, the complex should be cleavable or otherwise accessible under appropriate conditions within the cell so that the oligonucleotide is functional. (Gursel, *J. Immunol.* 167: 3324, 2001)

Opportunistic infection: An infection that occurs in an immunocompromised subject. Opportunistic infections may result from treatments or from alterations in the immune system. The infectious agent can be viral, bacterial, protozoan, or fungal. Opportunistic infections can include, but are not limited to bacterial infections such as salmonellosis, syphilis and neurosyphilis, turberculosis (TB), atypical mycobacterial infection, and bacillary angiomatosis (cat scratch disease), fungal infections such as aspergillosis, candidiasis (thrush, yeast infection), coccidioidomycosis, cryptococcal meningitis, and histoplasmosis, protozoal infections such as cryptosporidiosis, isosporiasis, microsporidiosis, *Pneumocystis Carinii* pneumonia (PCP), and toxoplasmosis, viral infections such as *Cytomegalovirus* (CMV), hepatitis, herpes

simplex (HSV, genital herpes), herpes zoster (HZV, shingles), human papiloma virus (HPV, genital warts, cervical cancer), *Molluscum Contagiosum*, oral hairy leukoplakia (OHL), and progressive multifocal leukoencephalopathy (PML), and neoplasms such as Kaposi's sarcoma, systemic non-Hodgkin's lymphoma (NHL), and primary CNS lymphoma, among others.

Pharmaceutical agent or **drug:** A chemical compound or composition capable of inducing a desired therapeutic or prophylactic effect when properly administered to a subject. Pharmaceutical agents include, but are not limited to, chemotherapeutic agents and anti-infective agents.

Pharmaceutically acceptable carriers: The pharmaceutically acceptable carriers useful in this disclosure are conventional. *Remington's Pharmaceutical Sciences*, by E. W. Martin, Mack Publishing Co., Easton, PA, 15th Edition (1975), describes compositions and formulations suitable for pharmaceutical delivery of the fusion proteins herein disclosed.

In general, the nature of the carrier will depend on the particular mode of administration being employed. For instance, parenteral formulations usually comprise injectable fluids that include pharmaceutically and physiologically acceptable fluids such as water, physiological saline, balanced salt solutions, aqueous dextrose, glycerol or the like as a vehicle. For solid compositions (for example, powder, pill, tablet, or capsule forms), conventional non-toxic solid carriers can include, for example, pharmaceutical grades of mannitol, lactose, starch, or magnesium stearate. In addition to biologically-neutral carriers, pharmaceutical compositions to be administered can contain minor amounts of non-toxic auxiliary substances, such as wetting or emulsifying agents, preservatives, and pH buffering agents and the like, for example sodium acetate or sorbitan monolaurate.

Purified: The term purified does not require absolute purity; rather, it is intended as a relative term. Thus, for example, a purified nucleotide preparation is one in which the nucleotide is more enriched than the nucleotide is in its natural

environment within a cell. Preferably, a preparation is purified such that the nucleotide represents at least 50% of the total peptide or protein content of the preparation.

Retroviruses: RNA viruses wherein the viral genome is RNA. When a host cell is infected with a retrovirus, the genomic RNA is reverse transcribed into a DNA intermediate which is integrated very efficiently into the chromosomal DNA of infected cells. The integrated DNA intermediate is referred to as a provirus. The term "lentivirus" is used in its conventional sense to describe a genus of viruses containing reverse transcriptase. The lentiviruses include the "immunodeficiency viruses" which include human immunodeficiency virus (HIV) type 1 and type 2 (HIV-1 and HIV-2), simian immunodeficiency virus (SIV), and feline immunodeficiency virus (FIV).

Self-complementary nucleic acid sequence: A nucleic acid sequence that can form Watson-Crick base pairs. The four bases characteristic of deoxyribonucleic unit of DNA are the purines (adenine and guanine) and the pyrimidines (cytosine and thymine). Adenine pairs with thymine via two hydrogen bonds, while guanine pairs with cytosine via three hydrogen bonds. If a nucleic acid sequence includes two or more bases in sequence that can form hydrogen bonds with two or more other bases in the same nucleic acid sequence, then the nucleic acid includes a self-complementary sequence.

Treatment: Refers to both prophylactic inhibition of initial infection, and therapeutic interventions to alter the natural course of an untreated disease process, such as infection with a virus (for example, HIV infection). "Preventing" a disease refers to inhibiting the full development of a disease, for example in a person who is known to have a predisposition to a disease such a person infected with HIV who does not exhibit the symptoms of AIDS. "Treatment" refers to a therapeutic intervention that ameliorates a sign or symptom of a disease or pathological condition, such as AIDS, after it has begun to develop.

Therapeutically effective dose: A dose sufficient to prevent advancement, or to cause regression of the disease, or which is capable of relieving symptoms caused by the disease, such as pain or swelling.

Vaccine: A preparation of attenuated microorganisms (including but not limited to bacteria and viruses), living microorganisms, antigen, or killed microorganisms, administered for the prevention, amelioration, or treatment of infectious disease.

Virus: A microscopic infectious organism that reproduces inside living cells. A virus consists essentially of a core of a single nucleic acid surrounded by a protein coat, and has the ability to replicate only inside a living cell. "Viral replication" is the production of additional virus by the occurrence of at least one viral life cycle. A virus may subvert the host cells' normal functions, causing the cell to behave in a manner determined by the virus. For example, a viral infection may result in a cell producing a cytokine, or responding to a cytokine, when the uninfected cell does not normally do so.

Unless otherwise explained, all technical and scientific terms used herein have the same meaning as commonly understood by one of ordinary skill in the art to which this disclosure belongs. The singular terms "a," "an," and "the" include plural referents unless context clearly indicates otherwise. Similarly, the word "or" is intended to include "and" unless the context clearly indicates otherwise. It is further to be understood that all base sizes or amino acid sizes, and all molecular weight or molecular mass values, given for nucleic acids or polypeptides are approximate, and are provided for description. Although methods and materials similar or equivalent to those described herein can be used in the practice or testing of this disclosure, suitable methods and materials are described below. The term "comprises" means "includes." All publications, patent applications, patents, and other references mentioned herein are incorporated by reference in their entirety. In case of conflict, the present specification, including explanations of terms, will control. In addition, the materials, methods, and examples are illustrative only and not intended to be limiting.

III. Description of Several Embodiments

A. D and K-type ODNs

The present disclosure relates to a class of DNA motifs that stimulates immune activation, for example the innate immune response or the adaptive immune response by B cells, monocytes, dendritic cells, and natural killer (NK) cells. K type CpG ODNs have been previously described (see U.S. Patent Nos. 6.194,388; 6,207,646; 6,214,806; 6,218,371; 6239,116, 6,339,068; 6,406,705, and 6,429,199, which are herein incorporated by reference). K ODNs that exhibit the greatest immunostimulatory activity share specific characteristics. These characteristics differ from those of the Formula II or D ODN (see below). In addition, K ODNs have specific effects on the cells of the immune system, which differ from the effects of D ODN. For example, K ODNs stimulate proliferation of B cells and stimulate the production of IL-6.

The K ODNs include at least about 10 nucleotides and include a sequence represented by Formula I:

5' $N_1N_2N_3$T-CpG-$WN_4N_5N_6$ 3' (SEQ ID NO: 20)

wherein the central CpG motif is unmethylated, W is A or T, and N_1, N_2, N_3, N_4, N_5, and N_6 are any nucleotides.

These Formula I or K ODNs stimulate B cell proliferation and the secretion of IgM and IL-6, processes involved in the body's humoral immunity, such as the production of antibodies against foreign antigens. In one embodiment, the K ODNs induce a humoral immune response.

Certain K oligonucleotides are of the formula:

5' $N_1N_2N_3$T-CpG-$WN_4N_5N_6$ 3' (SEQ ID NO: 20)

and contain a phosphate backbone modification. In one specific, non-limiting example, the phosphate backbone modification is a phosphorothioate backbone modification (for example, one of the non-bridging oxygens is replaced with sulfur, as set forth in International Patent Application WO 95/26204, herein incorporated by reference). In one embodiment, K ODNs have a phophorothioate backbone, and at least one unmethylated CpG dinucleotide. Eliminating the CpG dinucleotide motif from the K ODN significantly reduces immune activation. Incorporating multiple CpGs in a single K ODN increases immune stimulation. In some embodiments, the K ODNs are at least 12 bases long. In addition, K ODNs containing CpG motifs at the 5' end are the most stimulatory, although at least one base upstream of the CpG is required. More particularly, the most active K ODNs contain a thymidine immediately 5' from the CpG dinucleotide, and a TpT or a TpA in a position 3' from the CpG motif. Modifications which are greater than 2 base pairs from the CpG dinucleotide motif appear to have little effect on K ODN activity.

D ODNs differ both in structure and activity from K ODNs. The unique activities of D ODNs are disclosed below (see section C). For example, as disclosed herein, D oligodeoxynucleotides stimulate the release of cytokines from cells of the immune system. In specific, non-limiting examples D oligonucleotides stimulate the release or production of IP-10 and IFN-α by monocytes and/or plasmacytoid dendritic cells and the release or production of IFN-γ by NK cells. The stimulation of NK cells by D oligodeoxynucleotides can be either direct or indirect.

With regard to structure, a CpG motif in D oligonucleotides can be described by Formula II:

5' RY-CpG-RY 3' (SEQ ID NO: 21)

wherein the central CpG motif is unmethylated, R is A or G (a purine), and Y is C or T (a pyrimidine). D oligonucleotides include an unmethylated CpG dinucleotide.

Inversion, replacement, or methylation of the CpG reduces or abrogates the activity of the D oligonucleotide.

Certain D ODNs are at least about 16 nucleotides in length and includes a sequence represented by Formula III:

5' $X_1X_2X_3$ Pu_1 Py_2 CpG Pu_3 Py_4 $X_4X_5X_6(W)_M(G)_N$-3' (SEQ ID NOs: 22-98)

wherein the central CpG motif is unmethylated, Pu is a purine nucleotide, Py is a pyrimidine nucleotide, X and W are any nucleotide, M is any integer from 0 to 10, and N is any integer from 4 to 10.

The region Pu_1 Py_2 CpG Pu_3 Py_4 is termed the CpG motif. The region $X_1X_2X_3$ is termed the 5' flanking region, and the region $X_4X_5X_6$ is termed the 3' flanking region. If nucleotides are included 5' of $X_1X_2X_3$ in the D ODN, these nucleotides are termed the 5' far flanking region. Nucleotides 3' of $X_4X_5X_6$ in the D ODN are termed the 3' far flanking region.

In one specific non-limiting example, Py_2 is a cytosine. In another specific, non-limiting example, Pu_3 is a guanidine. In yet another specific, non-limiting example, Py_2 is a thymidine and Pu_3 is an adenine. In a further specific, non-limiting example, Pu_1 is an adenine and Py_2 is a tyrosine. In another specific, non-limiting example, Pu_3 is an adenine and Py_4 is a tyrosine.

In one specific not limiting example, N is from about 4 to about 8. In another specific, non-limiting example, N is about 6.

D CpG oligonucleotides can include modified nucleotides. Without being bound by theory, modified nucleotides can be included to increase the stability of a D oligonucleotide. Without being bound by theory, because phosphorothioate-modified nucleotides confer resistance to exonuclease digestion, the D ODN are "stabilized" by incorporating phosphorothioate-modified nucleotides. In one embodiment, the CpG dinucleotide motif and its immediate flanking regions include phosphodiester rather

than phosphorothioate nucleotides. In one specific non-limiting example, the sequence Pu_1 Py_2 CpG Pu_3 Py_4 includes phosphodiester bases. In another specific, non-limiting example, all of the bases in the sequence Pu_1 Py_2 CpG Pu_3 Py_4 are phosphodiester bases. In yet another specific, non-limiting example, $X_1X_2X_3$ and $X_4X_5X_6(W)_M(G)_N$ include phosphodiester bases. In yet another specific, non-limiting example, $X_1X_2X_3$ Pu_1 Py_2 CpG Pu_3 Py_4 $X_4X_5X_6(W)_M(G)_N$ include phosphodiester bases. In further non-limiting examples the sequence $X_1X_2X_3$ includes at most one or at most two phosphothioate bases and/or the sequence $X_4X_5X_6$ includes at most one or at most two phosphotioate bases. In additional non-limiting examples, $X_4X_5X_6(W)_M(G)_N$ includes at least 1, at least 2, at least 3, at least 4, or at least 5 phosphothioate bases. Thus, a D oligodeoxynucleotide can be a phosphorothioate/phosphodiester chimera.

As disclosed herein, any suitable modification can be used in the present disclosure to render the D oligodeoxynucleotide resistant to degradation *in vivo* (for example, via an exo- or endo-nuclease). In one specific, non-limiting example, a modification that renders the oligodeoxynucleotide less susceptible to degradation is the inclusion of nontraditional bases such as inosine and quesine, as well as acetyl-, thio- and similarly modified forms of adenine, cytidine, guanine, thymine, and uridine. Other modified nucleotides include nonionic DNA analogs, such as alkyl or aryl phosphonates (for example, the charged phosphonate oxygen is replaced with an alkyl or aryl group, as set forth in U.S. Patent No. 4,469,863), phosphodiesters and alkylphosphotriesters (for example, the charged oxygen moiety is alkylated, as set forth in U.S. Patent No. 5,023,243 and European Patent No. 0 092 574). Oligonucleotides containing a diol, such as tetraethyleneglycol or hexaethyleneglycol, at either or both termini, have also been shown to be more resistant to degradation. The D oligodeoxynucleotides can also be modified to contain a secondary structure (for example, stem loop structure). Without being bound by theory, it is believed that incorporation of a stem loop structure renders and oligodeoxynucleotide more effective.

In a further embodiment, Pu_1 Py_2 and Pu_3 Py_4 are self-complementary. In another embodiment, $X_1X_2X_3$ and$X_4X_5X_6$ are self complementary. In yet another embodiment $X_1X_2X_3$ Pu_1 Py_2 and Pu_3 Py_4 $X_4X_5X_6$ are self complementary.

Specific non-limiting examples of a D oligonucleotide wherein Pu_1 Py_2 and Pu_3 Py_4 are self-complementary include, but are not limited to, ATCGAT (SEQ ID NO: 9), ACCGGT (SEQ ID NO: 10), ATCGAC (SEQ ID NO: 11), ACCGAT (SEQ ID NO: 12), GTCGAC (SEQ ID NO: 13), or GCCGGC (SEQ ID NO: 14). Without being bound by theory, the self-complementary base sequences can help to form a stem-loop structure with the CpG dinucleotide at the apex to facilitate immunostimulatory functions. Thus, in one specific, non-limiting example, D oligonucleotides wherein Pu_1 Py_2 and Pu_3 Py_4 are self-complementary induce higher levels of IFN-γ production from a cell of the immune system (see below). The self-complementary need not be limited to Pu_1 Py_2 and Pu_3 Py_4. Thus, in another embodiment, additional bases on each side of the three bases on each side of the CpG-containing hexamer form a self-complementary sequence (see above).

One specific, non-limiting example of a sequence wherein Pu_1 Py_2 and Pu_3 Py_4 are self-complementary, but wherein the far-flanking sequences are not self-complementary is:

GGTGCATCGATACAGGGGGG (ODN D 113, SEQ ID NO:15).

This oligodeoxynucleotide has a far flanking region that is not self complementary and induces high levels of IFN-γ and IFN-α.

Another specific, non-limiting example of a D oligodeoxynucleotides is:

GGTGCGTCGATGCAGGGGGG (D28, SEQ ID NO: 16).

This oligodeoxynucleotide is of use for inducing production and/or release of cytokines from immune cells, although it lacks a self-complementary motif.

In one embodiment, the D oligodeoxynucleotides disclosed herein are at least about 16 nucleotides in length. In a second embodiment, a D oligodeoxynucleotide is at least about 18 nucleotides in length. In another embodiment, a D oligodeoxynucleotide is from about 16 nucleotides in length to about 100 nucleotides in length. In yet another embodiment, a D oligodexoynucleotide is from about 16 nucleotides in length to about 50 nucleotides in length. In a further embodiment, a D oligodeoxynucleotide is from about 18 nucleotides in length to about 30 nucleotides in length.

In another embodiment, the oligodeoxynucleotide is at least 18 nucleotides in length, and at least two Gs are included at the 5' end of the molecule, such that the oligodeoxynucleotide includes a sequence represented by Formula IV:

5' $GGX_1X_2X_3$ Pu_1 Py_2 CpG Pu_3 Py_4 $X_4X_5X_6(W)_M(G)_N$-3' (SEQ ID NOs: 99-175).

The D oligodeoxynucleotide can include additional Gs at the 5' end of the oligodeoxynucleotide. In one specific example, about 1 or about 2 Gs are included at the 5' end of an olgiodeoxynucleotide including a sequence as set forth as Formula IV.

Examples of a D oligodeoxynucleotide include, but are not limited to:

5'XXTGCATCGATGCAGGGGGG 3' (SEQ ID NO: 1)

5'XXTGCACCGGTGCAGGGGGG3' (SEQ ID NO: 2),

5'XXTGCGTCGACGCAGGGGGG3' (SEQ ID NO: 3),

5'XXTGCGTCGATGCAGGGGGG3' (SEQ ID NO: 4),

5'XXTGCGCCGGCGCAGGGGGG3' (SEQ ID NO: 5),

5'XXTGCGCCGATGCAGGGGGG3' (SEQ ID NO: 6),

5'XXTGCATCGACGCAGGGGGG3' (SEQ ID NO: 7),

5'XXTGCGTCGGTGCAGGGGGG3' (SEQ ID NO: 8),

wherein X any base, or is no base at all. In one specific, non-limiting example, X is a G. In particular, non-limiting examples, the oligodeoxynucleotide includes a sequence selected from the group consisting of SEQ ID NO: 1, SEQ ID NO: 2, SEQ ID NO: 3, SEQ ID NO: 4, SEQ ID NO: 5, SEQ ID NO: 6, SEQ ID NO: 7, SEQ ID NO: 8, SEQ ID NO: 9, SEQ ID NO: 10, SEQ ID NO: 11, SEQ ID NO: 12, SEQ ID NO: 13, SEQ ID NO: 14, SEQ ID NO: 15, and SEQ ID NO: 16.

The oligodeoxynucleotides disclosed herein can be synthesized *de novo* using any of a number of procedures well known in the art. For example, the oligodeoxynucleotides can be synthesized as set forth in U.S. Patent No. 6,194,388, which is herein incorporated by reference in its entirety. A D oligodeoxynucleotide may be synthesized using, for example, the B-cyanoethyl phophoramidite method or nucleoside H-phosphonate method. These chemistries can be performed by a variety of automated oligonucleotide synthesizers available in the market. Alternatively, oligodeoxynucleotides can be prepared from existing nucleic acid sequences (for example, genomic or cDNA) using known techniques, such as employing restriction enzymes, exonucleases or endonucleases, although this method is less efficient than direct synthesis.

B. Pharmaceutical Compositions

The immunostimulatory ODNs described herein may be formulated in a variety of ways depending on the type of disease to be treated. Pharmaceutical compositions are thus provided for both local use as well as for systemic use. Therefore, the disclosure includes within its scope pharmaceutical compositions comprising at least one immunostimulatory ODN formulated for use in human or veterinary medicine.

Pharmaceutical compositions that include at least one immunostimulatory ODN as described herein as an active ingredient, or that include both an immunostimulatory ODN and an additional anti-viral, immunomodulatory, or anti-infective agent as active ingredients, may be formulated with an appropriate solid or liquid carrier, depending upon the particular mode of administration chosen. Additional active ingredients include, for example, antivirals such as AL-721 (from Ethigen of Los Angeles, CA), recombinant human interferon beta (from Triton Biosciences of Alameda, CA), Acemannan (from Carrington Labs of Irving, TX), gangiclovir (from Syntex of Palo Alto, CA), didehydrodeoxythymidine or d4T (from Bristol-Myers-Squibb), EL10 (from Elan Corp. of Gainesville, GA), dideoxycytidine or ddC (from Hoffman-LaRoche), Novapren (from Novaferon Labs, Inc. of Akron, OH), zidovudine or AZT (from Burroughs Wellcome), ribavirin (from Viratek of Costa Mesa, CA), alpha interferon and acyclovir (from Burroughs Wellcome), Indinavir (from Merck & Co.), 3TC (from Glaxo Wellcome), Ritonavir (from Abbott), Saquinavir (from Hoffmann-LaRoche), and others, immuno-modulators such as AS-101 (Wyeth-Ayerst Labs.), bropirimine (Upjohn), gamma interferon (Genentech), GM-CSF (Genetics Institute), IL-2 (Cetus or Hoffman-LaRoche), human immune globulin (Cutter Biological), IMREG (from Imreg of New Orleans, LA), SK&F106528, TNF (Genentech), and soluble TNF receptors (Immunex), anti-infectives such as clindamycin with primaquine (from Upjohn, for the treatment of pneumocystis pneumonia), fluconazlone (from Pfizer for the treatment of cryptococcal meningitis or candidiasis), nystatin, pentamidine, trimethaprim-sulfamethoxazole, and many others, and agents used in HAART therapy, such as

nucleoside analog reverse transcriptase inhibitor drugs (NA), non-nucleoside analog reverse transcriptase inhibitor drugs (NNRTI), protease inhibitor drugs (PI).

The pharmaceutically acceptable carriers and excipients useful in this disclosure are conventional. For instance, parenteral formulations usually comprise injectable fluids that are pharmaceutically and physiologically acceptable fluid vehicles such as water, physiological saline, other balanced salt solutions, aqueous dextrose, glycerol or the like. Excipients that can be included are, for instance, proteins, such as human serum albumin or plasma preparations. If desired, the pharmaceutical composition to be administered may also contain minor amounts of non-toxic auxiliary substances, such as wetting or emulsifying agents, preservatives, and pH buffering agents and the like, for example sodium acetate or sorbitan monolaurate.

The dosage form of the pharmaceutical composition will be determined by the mode of administration chosen. For instance, in addition to injectable fluids, topical and oral formulations can be employed. Topical preparations can include eye drops, ointments, sprays and the like. Oral formulations may be liquid (for example, syrups, solutions, or suspensions), or solid (for example, powders, pills, tablets, or capsules). For solid compositions, conventional non-toxic solid carriers can include pharmaceutical grades of mannitol, lactose, starch, or magnesium stearate. Actual methods of preparing such dosage forms are known, or will be apparent, to those of ordinary skill in the art.

The pharmaceutical compositions that comprise an immunostimulatory ODN, in some embodiments, will be formulated in unit dosage form, suitable for individual administration of precise dosages. The amount of active compound(s) administered will be dependent on the subject being treated, the severity of the affliction, and the manner of administration, and is best left to the judgment of the prescribing clinician. Within these bounds, the formulation to be administered will contain a quantity of the active component(s) in amounts effective to achieve the desired effect in the subject being treated.

C. Therapeutic Uses

A method is disclosed herein for increasing an immune response to an opportunistic infection in an immunocompromised subject. Immunocompromised subjects are more susceptible to opportunistic infections, for example viral, fungal, protozoan, or bacterial infections, prion diseases, and certain neoplasms. Those who can be considered to be immunocompromised include, but are not limited to, subjects with AIDS (or HIV positive), subjects with severe combined immune deficiency (SCID), diabetics, subjects who have had transplants and who are taking immunosuppressives, and those who are receiving chemotherapy for cancer. Immunocompromised individuals also includes subjects with most forms of cancer (other than skin cancer), sickle cell anemia, cystic fibrosis, those who do not have a spleen, subjects with end stage kidney disease (dialysis), and those who have been taking corticosteroids on a frequent basis by pill or injection within the last year. Subjects with severe liver, lung, or heart disease also may be immunocompromised. The subject can be a human or a non-human mammal, such as a primate.

In some embodiments, the immunocompromised subject is infected with a lentivirus. Lentiviruses include, but are not limited to human immunodeficiency virus type 1 (HIV-1), human immunodeficiency virus type 2 (HIV-2), simian immunodeficiency virus agm (SIVagm), simian immunodeficiency virus mnd (SIVmnd), simian immunodeficiency virus syk (SIVsyk), simian immunodeficiency virus col (SIVcol), Visna-Maedi virus (VMV), bovine immunodeficiency virus (BIV), feline immunodeficiency virus (FIV), caprine arthritis-encephalitis virus (CAEV), and equine infectious anemia virus (EIAV). In some embodiments, the lentivirus is human immunodeficiency virus type 1 (HIV-1). In some embodiments, the lentivirus is human immunodeficiency virus type 2 (HIV-2).

In some embodiments, the opportunistic infection is infection with Leishmania major. In other embodiments, the opportunistic infection is a bacterial infection such as salmonellosis, syphilis and neurosyphilis, turberculosis (TB), atypical mycobacterial infection, and bacillary angiomatosis (cat scratch disease), a fungal infection such as

aspergillosis, candidiasis (thrush, yeast infection), coccidioidomycosis, cryptococcal meningitis, and histoplasmosis, protozoal infections such as cryptosporidiosis, isosporiasis, microsporidiosis, *Pneumocystis Carinii* pneumonia (PCP), and toxoplasmosis, or a viral infection such as *Cytomegalovirus* (CMV), hepatitis, herpes simplex (HSV, genital herpes), herpes zoster (HZV, shingles), human papiloma virus (HPV, genital warts, cervical cancer), *Molluscum Contagiosum*, oral hairy leukoplakia (OHL), and progressive multifocal leukoencephalopathy (PML), and neoplasms, such as Kaposi's sarcoma, systemic non-Hodgkin's lymphoma (NHL), and primary CNS lymphoma, among others.

In order to increase an immune response to an opportunistic infection in a subject infected with a lentivirus, a therapeutically effective amount of a D or K ODN (see above) is administered to the subject. In some embodiments, the oligodexoynucleotide is a D oligodeoxynucleotide, and in some examples, the oligodeoxynucleotide is at least about 16 nucleotides in length and comprises a sequence represented by the following formula:

5' $X_1X_2X_3$ Pu_1 Py_2 CpG Pu_3 Py_4 $X_4X_5X_6(W)_M$ $(G)_N$-3' (SEQ ID NOs: 22-98)

wherein the central CpG motif is unmethylated, Pu is a purine nucleotide, Py is a pyrimidine nucleotide, X and W are any nucleotide, M is any integer from 0 to 10, and N is any integer from 4 to 10. In particular examples of certain embodiments, N is about 6. In other examples, Pu Py CpG Pu Py includes phosphodiester bases, and in particular examples, Pu_1 Py_2 CpG Pu_3 Py_4 are phosphodiester bases.

In some embodiments, $X_1X_2X_3$ and $X_4X_5X_6(W)_M$ $(G)_N$ includes phosphodiester bases. In particular examples, $X_1X_2X_3$ includes one or more phosphothioate bases, and in other examples, $X_4X_5X_6(W)_M$ $(G)_N$ includes one or more phosphothioate bases. In still other embodiments $X_1X_2X_3$ Pu Py and Pu Py $X_4X_5X_6$ are self complementary, and in further embodiments, the lentiviral infection is treated in subject without stimulating expression of CD4 in T cells of the subject.

In some embodiments, the method includes administering to the subject a therapeutically effective amount of an immunostimulatory D oligodeoxynucleotide or an immunostimulatory K oligodeoxynucleotide, and an antigenic epitope of a polypeptide is not administered to the subject.

The method includes administering a therapeutically effective amount of a D oligodeoxynucleotide or a K oligodeoxynucleotide to a subject infected with a lentivirus, thereby treating the subject. In one embodiment, the ODN can be administered locally, such as by topical application or intradermal administration. For intradermal injection, for example, ODN are injected into the skin at the site of interest. ODNs can be injected, for example, once, or they may be injected in divided doses two or more times, for example monthly, weekly, daily, or 2-4 times daily. In other embodiments, the administration of the ODN is systemic. Oral, intravenous, intra-arterial, subcutaneous, intra-peritoneal, intra-muscular, inhalational, and even rectal administration is contemplated.

In some embodiments the method includes administering to the subject a therapeutically effective amount of an immunostimulatory D oligodeoxynucleotide or an immunostimulatory K oligodeoxynucleotide, and an antigenic epitope of a polypeptide is not administered to the subject. The method results in an increased response to an opportunistic infection.

D. Combination Therapy

The present methods also include combinations of the ODNs disclosed herein with one or more drugs useful in the treatment of an opportunistic infection. For example, the ODNs disclosed herein may be administered, whether before or after exposure to a virus, in combination with effective doses of other anti-virals, immunomodulators, anti-infectives, or vaccines. The term "administration" refers to both concurrent and sequential administration of the active agents.

In one embodiment, a combination of ODN with one or more agents useful in the treatment of a lentiviral disease is provided. In one specific, non-limiting example,

the lentiviral disease is an HIV-1-induced, an HIV-2-induced, a SIV-induced, or a FIV induced disease.

Specific, non-limiting examples of antivirals include: AL-721 (from Ethigen of Los Angeles, CA), recombinant human interferon beta (from Triton Biosciences of Alameda, CA), Acemannan (from Carrington Labs of Irving, TX), gangiclovir (from Syntex of Palo Alto, CA), didehydrodeoxythymidine or d4T (from Bristol-Myers-Squibb), EL10 (from Elan Corp. of Gainesville, GA), dideoxycytidine or ddC (from Hoffman-LaRoche), Novapren (from Novaferon Labs, Inc. of Akron, OH), zidovudine or AZT (from Burroughs Wellcome), ribavirin (from Viratek of Costa Mesa, CA), alpha interferon and acyclovir (from Burroughs Wellcome), Indinavir (from Merck & Co.), 3TC (from Glaxo Wellcome), Ritonavir (from Abbott), Saquinavir (from Hoffmann-LaRoche), and others.

Specific, non-limiting examples of immuno-modulators are AS-101 (Wyeth-Ayerst Labs.), bropirimine (Upjohn), gamma interferon (Genentech), GM-CSF (Genetics Institute), IL-2 (Cetus or Hoffman-LaRoche), human immune globulin (Cutter Biological), IMREG (from Imreg of New Orleans, LA), SK&F106528, TNF (Genentech), and soluble TNF receptors (Immunex).

Specific, non-limiting examples of some anti-infectives used include clindamycin with primaquine (from Upjohn, for the treatment of pneumocystis pneumonia), fluconazlone (from Pfizer for the treatment of cryptococcal meningitis or candidiasis), nystatin, pentamidine, trimethaprim-sulfamethoxazole, and many others.

"Highly active anti-retroviral therapy" or "HAART" refers to a combination of drugs that, when administered in combination, inhibits a retrovirus from replicating or infecting cells better than any of the drugs individually. In one embodiment, the retrovirus is a human immunodeficiency virus. In one embodiment, the highly active anti-retroviral therapy includes the administration of 3'axido-3-deoxy-thymidine (AZT) in combination with other agents, such as a D ODN. Specific, non-limiting examples of agents that can be used in combination in HAART for a human immunodeficiency virus are nucleoside analog reverse transcriptase inhibitor drugs (NA), non-nucleoside analog

reverse transcriptase inhibitor drugs (NNRTI), and protease inhibitor drugs (PI). One specific, non-limiting example of HAART used to suppress an HIV infection is a combination of indinavir and efavirenz, an experimental non-nucleoside reverse transcriptase inhibitor (NNRTI).

In one embodiment, HAART is a combination of three drugs used for the treatment of an HIV infection, such as the drugs shown in Table 2 below. Examples of three drug HAART for the treatment of an HIV infection include 1 protease inhibitor from column A plus 2 nucleoside analogs from column B in Table 2. In addition, ritonavir and saquinavir can be used in combination with 1 or 2 nucleoside analogs.

Table 2

Column A	Column B
indinavir (Crixivan)	AZT/ddI
nelfinavir (Viracept)	d4T/ddI
ritonavir (Norvir)	AZT/ddC
saquinavir (Fortovase)	AZT/3TC
ritonavir/saquinavir	d4T/3TC

In addition, other 3- and 4-drug combinations can reduce HIV to very low levels for sustained periods. The combination therapies are not limited to the above examples, but include any effective combination of agents for the treatment of HIV disease (including treatment of AIDS).

The disclosure is illustrated by the following non-limiting Examples.

EXAMPLES

Example 1

General Methods

Human PBMC:

Buffy coats from healthy blood donors were obtained from the NIH Department of Transfusion Medicine. PBMC from HIV infected subjects were obtained from the

Infectious Diseases Section of the Department of Transfusion Medicine at the National Institutes of Health Blood Bank and from the National Institute of Allergy and Infectious Diseases, NIH.

Rhesus monkeys:

Healthy 3 year old rhesus macaques (*M. mulata*) were obtained from the FDA colony in South Carolina. Animals were monitored daily by veterinarians. No systemic or local adverse reactions to CpG ODN were observed. Treatments were administered and peripheral blood samples obtained from ketamine anesthetized animals (10 mg/kg, Ketaject, Phoenix Pharmaceuticals, St Joseph, MD).

Mononuclear cell preparation:

Human and monkey mononuclear cells were isolated by density gradient centrifugation of PBMC over Ficoll-Hypaque as described. Cells were washed three times and cultured in RPMI 1640 supplemented with 10% heat-inactivated fetal calf serum (FCS), 1.5 mM L-glutamine and 100 U/ml of penicillin/streptomycin at 5 x 10^5 cells/well in the presence of 1-3 μM ODN. Supernatants were collected after 72 hours and tested by ELISA for cytokine and antibody levels.

Treatment groups and protocol:

For the first study 18 healthy rhesus macaques were challenged on the forehead on day 0 with 10^8 *L. amazonensis* (PH8) metacyclic promastigotes intradermally *(i.d.)* as previously described (R.Kenney *et al.*, 1999, *J. I.* 163:4481-4488; Verthelyi *et al.*, 2002, *J. I.* 168:1659-1663). Three days before and three days after the infectious challenge, monkeys (six per group) were treated *i.d.* at the site of the challenge with 500 μg of a mix of K or D ODN previously shown to stimulate rhesus macaques (Verthelyi *et al.*, 2002, *J. I.* 168:1659-1663). Control monkeys (n=6) received saline. The monkeys developed a typical self-limited lesion *in situ* characterized by erythema, induration, and ulceration. Lesion size, which reflects the severity of infection, was calculated from the

average diameter to approximate a circle, measuring length by width was measured weekly in a blinded fashion. For the second study, 14 monkeys that had been infected with SIV (SIVmac 239/CEMx174 CL#215; 100 MID_{50} intrarectally) one year before were challenged with 10^7 *L. major* metacyclic promastigotes (WHOM/IR/-/173). Three days before and three days after the challenge they were treated *i.d.* with D (n=4), K (n=4) or control (n=3) ODN at the site of challenge. Monkeys that received saline served as untreated controls. The size of the lesions and the viremia that developed was measured weekly. On day 56, the lesions were biopsied, the animals euthanized and the local and systemic parasitic load measured.

Experimental infections:

L. amazonensis (PH8) was obtained from American Type Culture Collection (Manasas, VA) and grown for infection. Promastigotes were grown in medium 199 with 20% FCS, supplemented by 0.1 mM adenine (Life Technologies, Gaithersburg, MD), 25 mM HEPES (Life Technologies), 5 µg/ml hemin (Sigma, St. Louis, MO), 1 µg/ml biotin (Life Technologies), and Pen/Strep/L-glutamine (Life Technologies). To ensure high infectivity, the strain was passed through BALB/c mice once and frozen as amastigotes for storage. These amastigotes were freshly transformed in culture to promastigotes, then grown to late log phase for each experiment. After washing the cells, metacyclic promastigotes were purified by negative selection using mAb D5, which recognizes a surface lipophosphoglycan determinant that is differentially expressed by procyclic and other immature stages of *L. amazonensis* promastigotes (E. Saraiva, unpublished). The promastigotes were incubated for 30 minutes at room temperature with a 1/200 dilution of D5 ascites, and the agglutinated parasites were pelleted by low-speed centrifugation at 400 x *g* for five minutes. Metacyclic promastigotes remaining in suspension were pelleted and washed, then resuspended at 1 x 10^8 promastigotes/ml in RPMI. Monkeys were challenged by injection with 1 x 10^7 metacyclic promastigotes in 0.1 ml in the forehead.

L. major clone V1 (MHOM/IL/80/Friedlin) promastigotes were grown at 26°C in medium 199 supplemented as described above. Infective-stage metacyclic promastigotes were isolated from 4-5 day old stationary cultures by negative selection using peanut agglutinin (Vector Laboratories, Burlingame, CA).

Oligodeoxynucleotides:

ODN were synthesized by the CBER Core Facility. All ODN had less than <0.1 EU of endotoxin per mg of ODN as assessed by a Limulus amebocyte lysate assay (QCL-1000, BioWhittaker). Individual humans and monkeys vary in their response to specific K and D ODNs. Indeed, no single D or K CpG motif is optimally stimulatory in all donors. However, mixtures of ODNs were identified that strongly stimulated PBMC from all human donors. These D or K ODN mixtures were used in the *in vivo* studies in macaques (Verthelyi *et al.*, 2002, *J. Immunology* 168:1659-1663).

Antibodies:

Cross-reactive Abs that recognized human and macaque IL-6 (R&D, Minneapolis, MN) and IFNγ (PBL Biomedical Laboratories, New Brunswick, NJ) were used in ELISA assays.

ELISA:

Microtiter plates (96-well, Millipore Corp., Bedford, MA) were coated with anti-cytokine Ab and blocked with PBS-5% BSA (Verthelyi *et al., J. Immunology,* 2001, 166:2372). Culture supernatants from PBMC cultures were added, and their cytokine content quantitated by the additional of biotin-labeled anti-cytokine Ab followed by phosphatase-conjugated avidin and phosphatase-specific colorimetric substrate. Standard curves were generated using known amounts of recombinant human cytokine. All assays were performed in triplicate. When supernatants from HIV/SIV-infected PBMC were used, Triton X100 was used to inactivate the virus.

Flow cytometry:

Cells cultured for various periods with D ODN were washed in cold PBS, fixed and stained with fluorescent labeled antibodies to CD83, CD86, CD14, MHC class II. Samples were washed and analyzed (20,000-40,000 events) on a FACScan flow cytometer (Becton Dickinson, San Jose, CA) after gating on monocytes with proper electronic compensation. The data were analyzed with CellQUest software Becton Dickinson).

Cell proliferation assay:

10^5 PBMC/well were incubated with 3 μM of ODN for 68 hours, pulsed with 1 μCi of [^{3}H] thymidine and harvested four hours later. All assays were performed in triplicate. Intraassay variation was <15%.

Viral load measurements:

Particle-associated SIV RNA in plasma was quantitated using a modification of a previously described real-time reverse transcription-PCR (RT-PCR) assay for SIV gag RNA, on a Prism 7700 sequence detection system (PE Biosystems, Foster City, Calif.). Specimen preparation and reverse transcription with random priming were as previously described (Silverstein *et al., J. Virol.* 2000 Nov; 74(22):10489-10497). For PCR amplification of the resulting cDNA, the following primers and biterminally labeled and 3'-blocked probe were used: forward primer (SGAG21), 5'-gTC TgC gTC ATP Tgg TgC ATT C-3' (SEQ ID NO: 17); reverse primer (SGAG22), 5'-CAC TAg KTg TCT CTg CAC TAT PTg TTT Tg-3'(SEQ ID NO: 18); and probe (P-SGAG23), 5'-(FAM)CTT CPT CAg TKT gTT TCA CTT TCT CTT CTg Cg(TAMRA) 3' (SEQ ID NO: 19), where P and K are modified bases (Glen Research catalog no. 10-1047-90 and 10-1048-90, respectively), introduced to minimize the impact of potential sequence mismatches at positions of described heterogeneity among SIV isolates (Los Alamos HIV sequence database, available on the internet), and FAM and TAMRA indicate the reporter fluorochrome 6-carboxy-fluorescein and the quencher fluorochrome 6-carboxy-

tetramethylrhodamine, respectively. After ten minutes at 95°C to activate the Taq Gold polymerase, 45 cycles of amplification were performed (consisting of 95°C for 15 and 60°C for 60 seconds), and the nominal SIV gag copy number for test specimens was determined by interpolation of the average measured threshold cycle number for duplicate determinations onto a standard curve of threshold cycle number versus known input template copy number for a purified *in vitro* transcript control template, essentially as described previously (Silverstein *et al., J. Virol.* 2000 Nov; 74(22):10489-10497).

The threshold sensitivity of the assay is 100 copy Eq/ml of plasma, with an average inter-assay coefficient of variation of <25%.

Statistical Analysis:

Statistically significant differences in cytokine and cell proliferation levels were determined using a 2-tailed non-parametric Rank Sum test or ANOVA with Dunnett's post test analysis. Differences in lesion sizes were tested by Friedman Repeated-Measures Analysis on Ranks with Tukey's All Pairwise Multiple Comparison Procedure using Sigma Stat.

Example 2

Immunoprotective activity of CpG ODN *in vivo:*

Previous studies had established that treatment with CpG ODN protected mice from up to 10^4 L metacyclic parasites). In order to determine whether CpG ODNs were able to exert a similar protective effect in primates we utilized a non-human primate model for leishmaniasis. Eighteen rhesus macaques were treated with 500 μg of either D or K CpG ODN mixes previously shown to be active on PBMC of non-human primates (Verthelyi *et al.*, 2002, *J. I.* 168:1659-1663). *In situ* intradermal (i.d.) inoculation was carried out three days before and three days after challenge with *L. amazonensis* in the skin of the forehead. As previously described, intradermal inoculation with 10^8 *L. amazonensis* induced the development of a cutaneous

Leishmania lesion that resembles the ones observed in humans. In untreated monkeys its peak surface area was of 14 ± 10 mm^2 on day 22. As shown in FIG. 2, treatment of the macaques with D ODN, but not with K ODN, significantly reduced the size of the cutaneous lesion ($p<0.001$). This shows that treatment of primates with CpG D ODN protect them from a local challenge with pathogenic *Leishmania* parasites.

Example 3

PBMC from HIV infected subjects respond to CpG ODN

HIV infection is associated with a progressive loss of immune function and increased susceptibility to opportunistic infections such as *L. major*. In addition to the gradual loss of $CD4^+$T cells, there is a reduction in number and function of plasmacytoid dendritic cells (pDC) and natural killer (NK) cells leading to impaired immune responses and increase susceptibility to opportunistic infections (Chehimi, 2002, *J. I.* :168: 4796-4801; Azzoni *et al.*, 2002 *J. I.* 168:5764-5770). In order to assess whether PBMC from HIV infected patients would be responsive to CpG ODN activation, the response of PBMC from 43 HIV-infected (Table 3) and 16 healthy individuals to D and K CpG ODN was compared *in vitro*.

As previously shown, the response elicited by PBMC from healthy subjects to the two types of CpG ODN was distinct: D ODN triggered the secretion of IFNα and IFNγ (FIG. 3), and induced DC maturation (FIG. 4). In contrast, K ODN increased cell proliferation and IL-6 production (FIG. 3). PBMC from healthy and HIV infected subjects secreted similar levels of IFNα and IFNγ in the absence of stimulation or in the presence of control ODN lacking the CpG motif (FIG. 3). Upon stimulation with CpG D ODN, however, PBMC from HIV infected subjects generated significantly lower IFNγ ($p<0.05$) or IFNα than healthy controls ($p<0.001$) (FIG. 3). The reduction in IFNα and IFNγ secretion correlated directly with the number of CD4+ T cells ($p<0.01$) (FIG. 5) and inversely with viral load ($p<0.05$), but did not correlate with the number of $CD56^+$ NK cells or $CD14^+$ monocytes. The reduced response to D ODN did not associate with antiretroviral therapy (ART).

Table 3 Description of HIV-infected PBMC Donors

		<200	200-500	>500
number		9	17	17
age		40 +/- 2	39 +/- 1	37 +/- 2
race	white	4	13	8
	black	4	4	7
	hispanic	1	1	2
gender	male	8	15	17
	female	0	2	0
CD4		25 +/- 7	317 +/- 20	735 +/- 67
%CD4T		3 +/- 1	21 +/- 1.9	31 +/- 3
Avg. VL		27000 +/- 50000	1828 +/- 29000	663 +/- 330
Range VL		50-75 x 10^8	50-5 x 10^8	ND-35000
NK $CD56^+/CD16^+$		9 +/- 2	8.3 +/- 1	5.6 +/- 1.6
%CD14		19 +/- 2	22 +/- 1	15.6 +/- 3
%CD19		19 +/- 5	14 +/- 1	9 +/- 2
% on HAART		66	66	80

CPG D ODNs induce monocytes to mature into $CD83^+$ $CD86^+$ DC *in vitro*. Fewer mature DC were evident in PB from HIV infected patients, especially in those with higher viral loads. However, upon stimulation with CpG D ODN, a 10-fold increase in the number of mature DC was apparent.

The response to K ODN was not significantly different in PBMC from HIV infected and healthy subjects (FIG. 3) indicating that B cells and monocytes retain their ability to respond to CpG ODN. Together these data show that PBMC from HIV infected subjects are activated by CpG ODN *in vitro*. The responsiveness to CpG ODN,

although reduced, is evident even among patients with high viral loads and low CD4+T cells.

Example 4

PBMC from SIV infected rhesus macaques respond to CpG ODN

Rhesus macaques are a relevant animal model for testing the activity of CpG ODN planned for human use. It has been demonstrated that D and K ODN elicit a cytokine profile in PBMC of rhesus macaque that is similar to the one generated in human PBMC. To assess whether PBMC from rhesus macaques infected with SIV would respond to CpG ODN *in vitro*, PBMC from 16 SIV infected and 20 healthy macaques were stimulated *in vitro* with D and K CpG ODN. As observed with PBMC from HIV infected patients, PBMC from SIV infected macaques showed a response to CpG K ODN stimulation *in vitro* that was indistinct from that of healthy macaques (FIG. 6). Stimulation with CpG D ODN, in turn, generated significantly increased levels of IFNα, although the magnitude of the IFNα response was reduced when compared with PBMC from healthy macaques.

Example 5

CpG ODN protect SIV infected non-human primates from a cutaneous infection with *L.major*

To assess whether the response to CpG ODN generated in immunosuppressed HIV patients would suffice to generate an immunoprotective response *in vivo*, 14 rhesus macaques that had been infected with XX SIV strain mac239 a year before the start of the study (Viral load range: 0.3-28 $x10^6$ copies/ml) were utilized. Monkeys were treated *i.d.* with D ODN (n=4), K ODN (n=4), control ODN (n=3) or saline 3 days before and 3 days after an intra-dermal challenge with 10^7 viable metacyclic promastigotes of *L. major* (WHOM/IR/-/173), a strain of *Leishmania* that frequently infects HIV patients. As shown in FIG. 7, control monkeys developed a typical self-limited *in situ* lesion characterized by erythema, induration, and ulceration. The lesion

size, which reflects the severity of infection (Amaral, *et al.*, 1996, *Exp. Parasitol.* *82*:34), was measured weekly. Monkeys treated with CpG D ODN had significantly smaller lesions than control or K ODN treated monkeys. On day 56 the monkeys were euthanized and the local and systemic parasite burden measured. Monkeys treated with D ODN appeared to have a 1 log reduction in parasite burden at the lesion site compared to the ones treated with control ODN or saline but the difference did not reach statistical significance. No systemic diffusion of the parasites were evident on any of the groups.

Lastly, since vaccination and infection can activate the immune cells and lead to an increase in viremia, the viral load of the macaques was assessed every 2 weeks throughout the study. No significant change in viral load was evident in any of the groups.

Example 6

CpG ODN protect p47phox-/- mice from infection with *Listeria*

p47phox-/- mice exhibit a phenotype similar to that of human chronic granulomatous disease (CGD). The biochemical basis for CGD is a defect in the phagocyte nicotine amide dinucleotide phosphatase (NADPH) oxidase, the enzyme responsible for producing superoxide O-2, which in turn is critical for host defense against bacterial and fungal infection. Mice were treated with CpG or saline 3 days before and 3 days after a challenge with *Listeria* bacteria. Mice pre-treated with CpG D ODNs showed a 20% increase in protection against *Listeria* as compared to those treated with control ODN or saline.

Example 7

PBMC from subjects with human chronic granulomatous disease (CGD) respond to CpG ODN

The biochemical basis for CGD is a defect in the phagocyte nicotine amide dinucleotide phosphatase (NADPH) oxidase, the enzyme responsible for producing superoxide O-2, which in turn is critical for host defense against bacterial and fungal

infection. In order to assess whether PBMC from subjects with CGD are responsive to CpG ODN activation, the response of PBMC from subjects with CGD and healthy individuals to D and K CpG ODNs is compared *in vitro*. The response elicited by PBMC from healthy subjects to the two types of CpG ODN is distinct: D ODN trigger the secretion of IFNα and IFNγ, and induce DC maturation. In contrast, K ODN increase cell proliferation and IL-6 production. IFNα and IFNγ levels in PBMC from healthy and subjects with CGD are measured as described above following stimulation with D and K CpG ODN.

Example 8

CpG Oligonucleotides improve the response to hepatitis B immunization in healthy and SIV infected rhesus macaques

Development of an immunogenic vaccine against hepatitis B is particularly important for HIV infected patients. Since shared epidemiological risks result in HIV infected subjects having a high incidence of HBV, and co-infection with HBV increases the rate of hepatotoxicity of HAART. Although HBV vaccination is recommended to all HIV patients, its efficacy in these patients is reduced. This example compares the adjuvant effect of K and D type ODN as vaccine adjuvants to the hepatitis B vaccine and compares their effectiveness immunocompromised SIV infected rhesus macaques.

ODNs were synthesized as follows:

D19: GGtgcatcgatgcagGGGGG (SEQ ID NO: 176)

D35: GgtgcatcgatgcaggggGG (SEQ ID NO: 177)

D29 : GGtgcaccggtgcagGGGGG (SEQ ID NO: 178)

K3: ATCGACTCTCGAGCGTTCTC (SEQ ID NO: 179)

K123: TCGTTTGTTCT (SEQ ID NO: 180)

K23: TCGAGCGTTCTC (SEQ ID NO: 181)

Phosphorothioate bases are shown in capital letters; phosphodiester bases in lower case. All ODN had less than <0.1 EU of endotoxin per mg of ODN as assessed by a Limulus amebocyte lysate assay (QCL-1000, BioWhittaker). Due to individual

heterogeneity in the response to specific "K" and "D" sequences mixtures of ODN were used in *in vivo* studies.

Two to three year old rhesus macaques (*M. mulata*) were obtained from the FDA colony in South Carolina. Animals were monitored daily by veterinarians. No systemic or local adverse reactions to CpG ODN were observed.

SIV plasma RNA levels were determined by a real time RT-PCR assay, as described in Example 1. IgG antibodies to HBs were assessed as per manufacturer's instructions and quantitated using IgG anti-Hepatitis B surface antigen (anti-HBs, DiaSorin, Saluggia, Italy). Spearman's correlations were used to assess the relationship between viral load and response to ODN. Differences in antibody titers over time were tested by Friedman Repeated-Measures Analysis on Ranks with Tukey's All Pairwise Multiple Comparison Procedure using Sigma Stat (SPSS, San Rafael, CA). Differences in viral load were tested by t test of log-normalized data.

To compare the efficacy of D and K type ODN as adjuvants for the vaccine against hepatitis B, 15 two year-old rhesus macaques weighing 6 +/- 1 lbs. (five per group) were immunized with the pediatric dose of Engerix B containing 10 μg of HBsAg adsorbed to alum alone or together with 250 μg of D or K type ODN. The animals were boosted 30 and 60 days later with the same product. All monkeys were negative for antibodies to HbsAg at baseline. Fourteen days after the first immunization, all macaques vaccinated with Engerix-B - D ODN had antibodies to HBV greater than 10mIU/ml, compared to only 60 and 80 % of those immunized with Engerix B- K ODN or Engerix B alone respectively. All animals developed protective levels (>10mIU/ml) of antibodies to HBV after the first boost. As shown in FIG. 8, animals that received K or D ODN as adjuvants developed significantly higher antibody levels (peak titer : 20469 +/- 2240 and 21702 +/- 1764 for K and D ODN respectively, compared to 9226 +/- 5237 for those animals that received the vaccine alone, $p = 0.012$). D and K type CpG ODN were equally effective as vaccine adjuvants for the hepatitis B vaccine.

Next, the efficacy of CpG ODN in eliciting a similar increase in antibodies to HbsAg in SIV infected rhesus macaques was assessed. Seventeen SIV infected animals were immunized with a pediatric dose of Engerix-B alone or together with 250 μg of D or K ODN. The animals were boosted 30 and 75 days after prime. The levels of IgG anti-HbsAg in sera were measured every two weeks for four months. Unlike healthy macaques, SIV infected animals were unable to mount a protective antibody response when immunized with the commercial hepatitis B vaccine alone, even after three immunizations. Only 20% of the animals immunized with Engerix B alone had antibody levels greater than 10mIU/ml, and the mean peak level of antibodies produced was 9 +/- 7 mIU/ml. Among the animals that received the vaccine together with D or K ODN, the antibody titers achieved were inversely correlated with monkey's viral load at the start of the study (FIG. 9A). Indeed, animals with viral loads greater than $1x10^7$ copies/ml at the time of immunization were unable to mount a protective response to the vaccine regardless of the adjuvant used. Among those that had viral loads greater than 10^7 copies/ml, K and D ODN were similarly effective at promoting the development of anti-HbsAg antibodies (FIG. 9B). Although the antibody levels achieved were significantly increased relative to those macaques receiving the HBV vaccine alone, their absolute levels were significantly lower than those developed by healthy macaques ($p<0.001$).

No significant increases in viral load were observed for any of the groups during this experiment, indicating that at this dose, CpG ODN do not appear to impact viral replication.

As demonstrated in this example, addition of K or D ODN boosts the immunogenicity of the HBV vaccine to render refractory SIV infected macaques responsive to vaccination. There is a pressing need for the development of an immunogenic vaccine against hepatitis B that is effective in HIV infected patients. These findings indicate that addition of CpG ODN to commercially available vaccines may allow patients with low or moderate viral loads to mount a protective response.

It will be apparent that the precise details of the methods or compositions described may be varied or modified without departing from the spirit of the described disclosure. We claim all such modifications and variations that fall within the scope and spirit of the claims below.

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